DEVELOPMENT OF ARTERY MODELS FOR PATIENT-SPECIFIC SIMULATIONS OF CORONARY STENTING: A SIX-CASE STUDY

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Introduction

In recent years, *in silico* analyses have gained increasing attention as a powerful tool to support clinical decision-making. In the context of coronary stenting, simulations can be used to predict the effects of complex treatments, furnish supplementary comprehension regarding post-treatment hazards, and reduce the need for animal and clinical studies during the development and assessment phases of a new device. As a result, computational studies have become an essential part of medical research, opening the issue of establishing the credibility of stent and coronary artery models used in simulations. Various studies have explored different strategies to mechanically describe arterial tissues, ranging from simple homogeneous approaches [1, 2] to more complex fiber-reinforced models [3]. In this work, we aim to discuss different modeling methods, including the representation of arterial tissue softening due to damage at high deformations, and assess the ability of these models to reproduce the stenting procedure of six patient-specific cases. Specifically, it is intended to evaluate the models' abilities to replicate clinical outcomes such as postoperative vessel lumen area and prediction of the presence of any malapposition.

Materials and Methods

The arterial models of each patient were obtained through reconstructions based on clinical images (OCT and angiographies). Through the analysis of these images, it was possible to differentiate the adventitia and media layers in the model, as well as different components of atherosclerotic plaque, such as calcifications, lipid pools, and generic plaque. The mechanical description followed the approaches proposed in a previous literature work [4], with the additional incorporation of a phenomenological damage model that can replicate the gradual mechanical deterioration of arterial tissues under high deformations. All the simulations were carried out in Abaqus/Explicit, with the hypothesis of working in quasi-static regime and faithfully replicating the stent deployment procedure adopted for the treatment of each patient.

Results

In comparison with post-stenting clinical data (Figure 1), the developed damage model was demonstrated to be effective in replicating what was observed in correspondence with high values of lumen gain, where the reference model (NoDamage) fails to predict the post-treatment lumen area. As reported in Figure 2, the approach proposed in this study has also proved to be effective in predicting areas of stent strut malapposition.

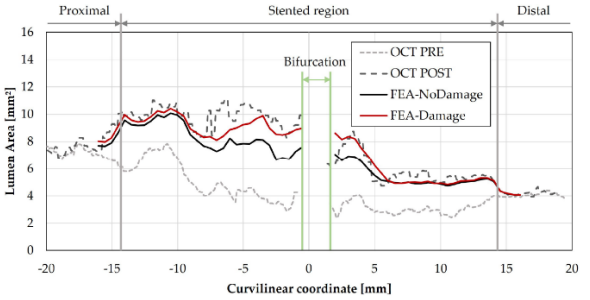

Figure 1: Comparison between the computational results (with and without the damage model), with respect to lumen area values acquired from OCT slices.

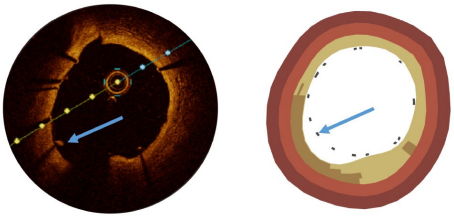

Figure 2: Detection of malappositions: comparison between OCT slice (on the left) and simulation cross-section (on the right).

Discussion

Despite using a phenomenological approach, the mechanical description of arterial walls has demonstrated to be robust and valid in reproducing, with good approximation, the results observed in six clinical cases. Incorporating the damage description, the previous model's capability to accurately reproduce the behavior at low deformations was preserved, providing also realistic performance even when high lumen gain values were encountered.

References

1. Chiastra, C. et al, J Biomech, 49:2102–2111, 2016.
2. Zhao, S. et al, Scientific Reports, 11, 2021.
3. Mortier, P. et al, Ann of Biomed Eng, 38(1):88–99, 2010.
4. Poletti et al, Electronics, 11(3):502, 2022.

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